APPENDIX E
DESIGN EXAMPLES

The following hypothetical example illustrates the approach and procedure used for the calculation and design of a landfill gas collection system for a 12-acre municipal landfill. This model can be used for mixed and hazardous waste landfills, however, consideration for the composition of the refuse must be factored into the calculations for gas production potential as well as the handling of off-gas.

The following example is hypothetical. The following parameters for the hypothetical site were selected:

Site Characteristics

- Landfill Footprint: 12 acres
- Maximum Depth at Center point: 70 feet
- Landfill Side Slope: 3:1 horizontal:vertical
- Landfill Top Slope: 5 %
- Landfill cover area: 620,000 ft^2

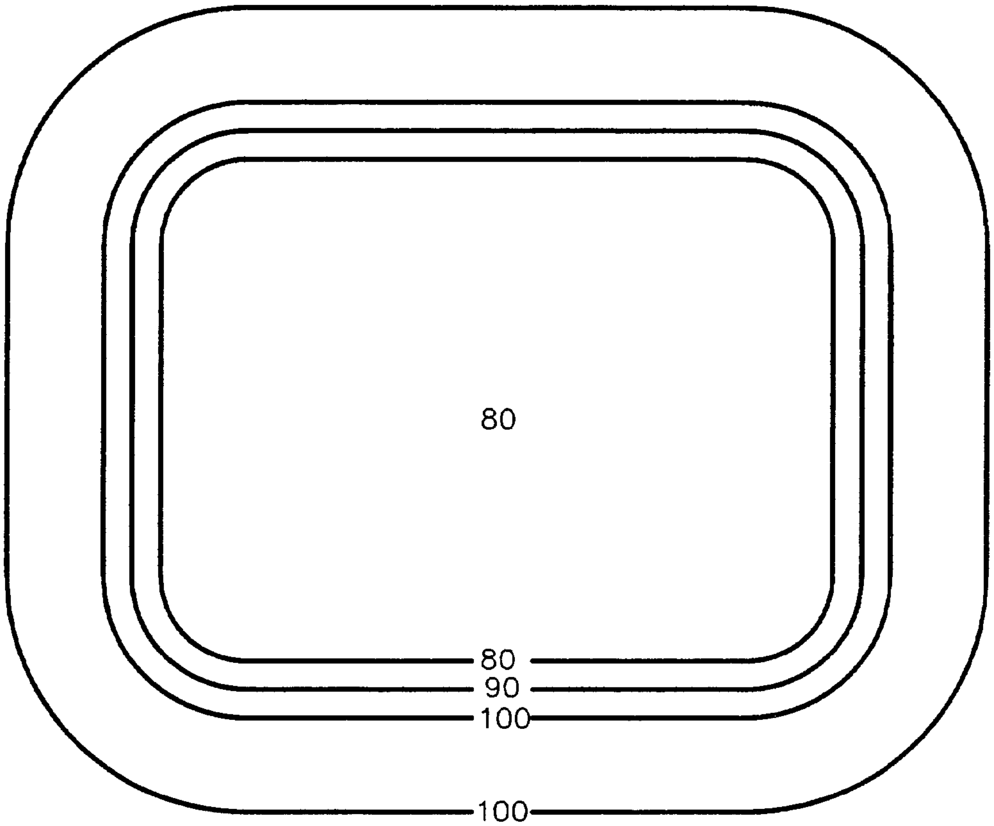
Refuse Characteristics

- Ratio of Refuse/Cover Material: 4:1
- Age of Refuse: 20 years
- In-Place Refuse Density: 800 $\#/yd^3$
- Capping Material: 40 mil HDPE
- Refuse Void Ratio: 4 %

Gas Characteristics

- Gas Constant: 0.08 yr^{-1}
- Gas Production Potential: 7400 ft^3/ton
- Concentration of Methane in Gas: 50 %
- Radius of Influence/Well: 200 ft
- Vacuum Pressure at Wellhead: 10 in wc
- Temperature of Landfill Gas: 110 ^0F
- Landfill Gas Viscosity: 2.8E-7 lbs.sec/ft^2
- Landfill Gas Density: 7.6E-2 lbs/ft^3

Figure E-1 illustrates the Model Landfill Base Grade Plan.



BASE GRADE PLAN

FIGURE E-1

MODEL LANDFILL
N.T.S.

1. Estimate Volume of Refuse in Landfill

Assumptions:

- Pre-landfill development topography and final topography are available, see E-l,
- No historical records are available for estimating rate of filling at the site

Methodology:

- Calculate landfill volume using geometry or computer-aided design software
- Estimate in-place volume of refuse based on ratio of waste: cover material
- Estimate tonnage of refuse based on estimated refuse density

Calculations

Compute landfill volume using computer aided design (CAD) software.

Datum (DTM) to Datum Volume
Cut and Fill Volumes
CAD Output

Shrinkage/swell factors:		Cut: 1.0000	Fill: 1.0000
Original DTM Layer Name	# of Points	Final DTM Layer Name	# of Points
EG	176	FG	400

Cut Volume (CY)	Cumulative Cut Volume	Fill Volume (CY)	Cumulative Fill Volume
0.0	0.0	872,826.6	872,826.6

Volume of Refuse Calculation:

Total cumulative fill volume = 872,827 CY

Assuming a-12" intermediate/final cover is currently constructed across entire landfill area.

-Volume of Intermediate/Final Cover:

$620{,}000\ ft^2 \times 1ft \times \frac{CY}{27\ ft^3} =$ 22,962 CY

Assuming there are 6 layers of refuse.

-Total cover material:

22,962 CY x 6 - 137,772 CY

-Volume of Refuse:

872,827 CY - 137,772 CY = 735,055 CY

Assuming refuse density of 800#/CY (poorly compacted)

-Tonnage of refuse:

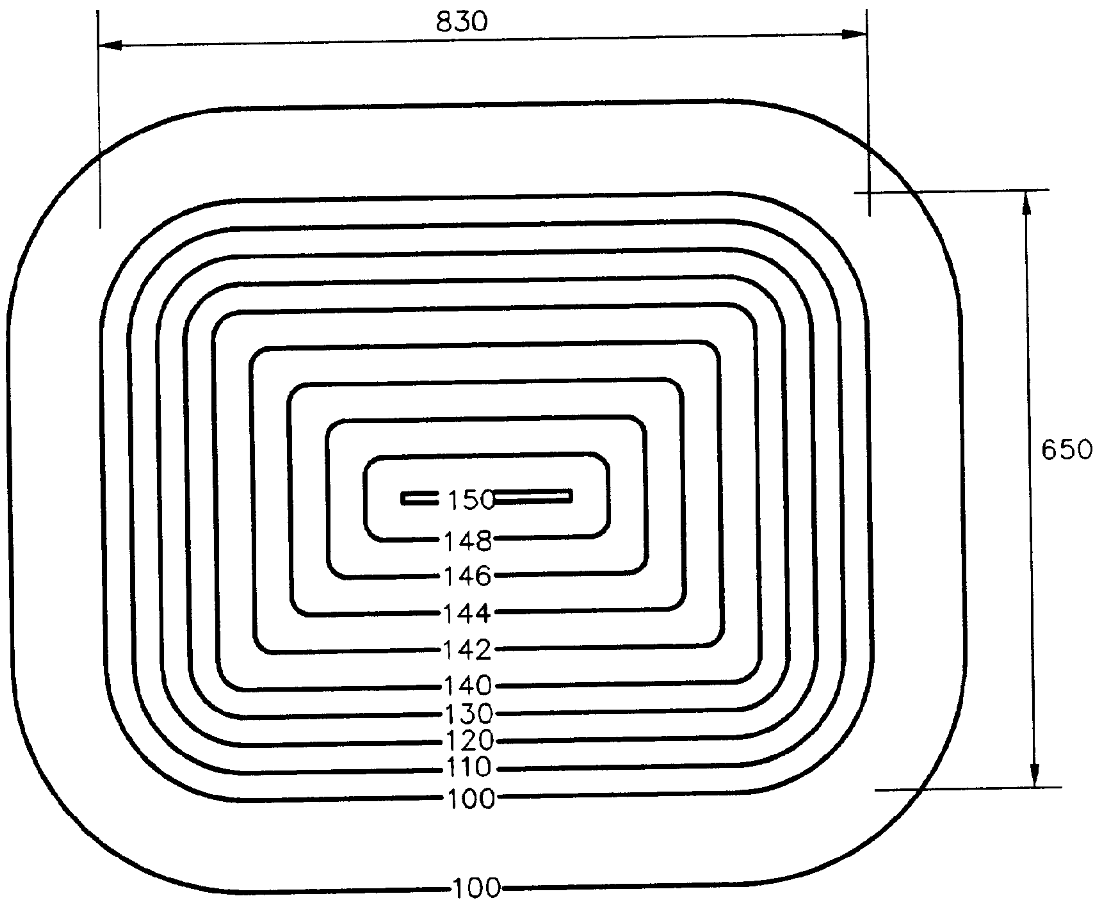
$735{,}055\ CY \times \frac{800\#}{CY} \times \frac{1ton}{2000\#} =$ 294,022 ton

Assuming regular increment of refuse displacement over 15 year life of landfill.

-Annual refuse acceptance to landfill:

$\frac{294.022\ ton}{15\ yr} =$ 19,600 ton/yr

The Model Landfill Final Fill Plan is illustrated in Figure E-2.



FINAL FILL PLAN

FIGURE E-2

MODEL LANDFILL
N.T.S.

2. Estimation of Landfill Gas Generation

Assumptions:

- Waste composition can be approximated by average municipal waste composition data compiled by the U.S. EPA

- Landfill setting is a humid environment establishing conditions affecting biological degradation

- Landfill gas generation is due principally to anaerobic bacteria and can be simulated by first order kinetics

Methodology:

- Use Scholl Canyon Model assuming waste was deposited in equal increments annually over the active life of the landfill

- Assume refuse was deposited at regular increments over the 15-year period

3. Gas generation rate calculation

Method 1: SCHOLL CANYON MODEL

Formula: Q = 2*[k*L*R[exp(-K*(t-lag))]

where:

Q = landfill gas generation rate @ time t (ft^3/yr).
L = potential gas generation capacity of refuse (ft^3/ton)
R = annual refuse acceptance rate in landfill (tons/yr)
k = gas generation rate, or refuse decay rate (1/yr)
t = time since refuse placement (yr)
lag = time to reach anaerobic conditions (yr)

Input parameters:

L = 7400	Year closed	=	1990
k = 0.08	Current Year	=	1995
lag = 2	Time Since Closure	=	5
	Avg. refuse	=	18,620 ton yr

Year	Time Since Refuse placement	Generation Date 1995
1975	20	5.22E+06
1976	19	5.66E+06
1977	18	6.13E+06
1978	17	6.64E+06
1979	16	7.19E+06
1980	15	7.79E+06
1981	14	8.44E+06
1982	13	9.14E+06
1983	12	9.91E+06
1984	11	1.07E+07
1985	10	1.16E+07
1986	9	1.26E+07
1987	8	1.36E+07
1988	7	1.48E+07
1989	6	1.60E+07
1990	--	0.00E+00
1991	--	0.00E+00
1992	--	0.00E+00
1993	--	0.00E+00
1994	--	0.00E+00
1995	--	0.00E+00
TOTAL ANNUAL CURRENT PRODUCTION		1.46×10^8 ft^3/yr $4.13 \times 10^6 m^3/yr$ $7.86 m^3/min$

4. Radius of Influence/Well System Layout&

Assumptions:

- ! No pilot scale test data is available

Methodology:

- ! Use EPA default diameter of influence of 200'
- ! Divide landfill area by area of influence of one well to obtain number of wells
- ! Establish layout of wells using the estimated coverage of each well predicted by the 200' diameter of influence

Well System Layout Calculation:

Assume:

Surface Area ≈ 620,000 ft^2
Diameter of Influence = 200 ft
Area of Influence = $\frac{Bd^2}{4} = \frac{B(200)^2}{4} = 31,400 ft^2$

$$\text{Number of Wells Required} = \frac{\text{Area of Landfill}}{\text{Area of Influence}}$$

$$= \frac{620\ 000\ ft^2}{3l,400 ft^2} = 19.74 \text{ say 20 Wells}$$

Well System layout is presented in Figure E-3.

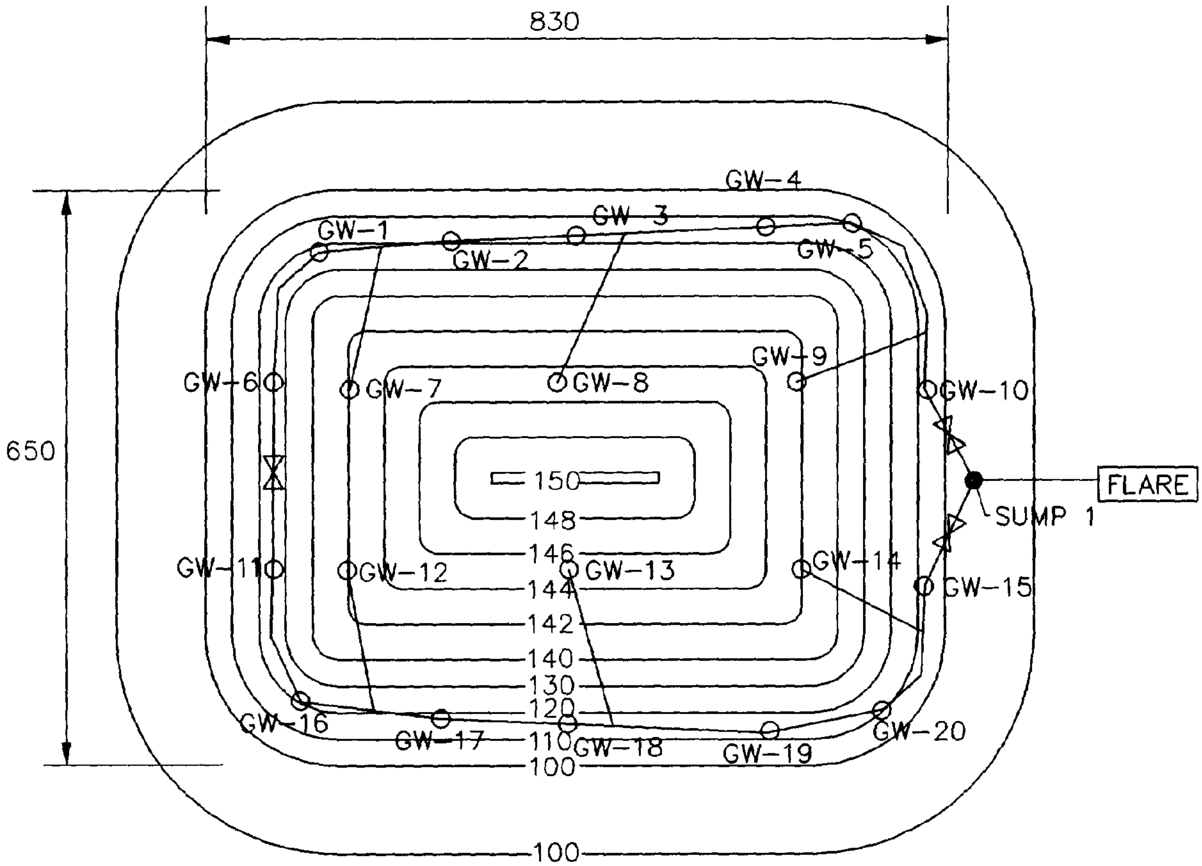


FIGURE E-3

MODEL LANDFILL
GAS WELL SYSTEM LAYOUT

LEGEND

- GAS EXTRACTION WELL
- SUMP
- GAS LATERAL
- IN-LINE ISOLATION VALVE/ MONITORING STATION

Radius of Influence Equation - Intrinsec Permeability

Input Variable	Unit	Wells	
		G-12	G-16
Landfill Depth, L	ft	65	45
Landfill Capacity, M	lbs	5.59E+06	5.59E+06
Screen Length, WD	ft	55	35
Ratio of well depth to landfill depth, WD/L	ft/ft	0.85	0.78
Efficiency of Collection, Ea	%	100	100
Flowrate, Q	cfm	277	277
Viscosity of landfill gas, mu	lb min/ft^2	4.21E-09	4.21E-09
Density of refuse, rho	lb/ft^3	29.63	29.63
Extraction well radius, r	ft	0.75	0.75
Maximum well vaccuum (gage), Pv	lbs/ft^2	26.02	26.02
Internal pressure of landfill (gage), Pl	lbs/ft^2	21.2	21.2
Radius of Influence, R	ft	100	100
Output Variable Intrinsic permeability of refuse, k	ft^2 (m^2)	4.07E-08	4.43E-08

EQUATIONS: (Pl^2 -Pv^2)/Pv = (R^2 ln(R/r) mu rho Q Ea)/ (M k (WD/L))

solve for k: k = (R^2 ln(R/r) mu rho Q (Ea/100))/((Pl^2 - Pv^2)/Pv) M (WD/L))

6. Sizing of Header Pipe in Gas Collection system

Assumptions:

- Minimum pipe diameter is 4 inches
- Pipe is constructed of HDPE or similar polymer

Methodology:

- Estimate cumulative gas flow rates for each length of header

- Estimate diameter of header assuming use of a minimum velocity through the header system (2000 ft/s)

- Divide cumulative gas flow rate for each length of header by 2000 ft/s to establish the diameter of the pipe

Calculations:

The Gas Extraction Well System Calculations can be found on pages E-12 thru E-14.

7. Sizing of Landfill Gas Blower

Assumptions.

- Gas parameters as noted above

- Relative roughness of HDPE pipe can be approximated by the relative roughness of "smooth pipes" on the Moody Diagram(14).

- Fittings losses as obtained from manufacturer's data

Methodology

- Calculate the velocity through each header section

- Calculate velocity head for each header section

- Estimate head loss due to friction for each header section

- Estimate vacuum at the well head using figure E-4

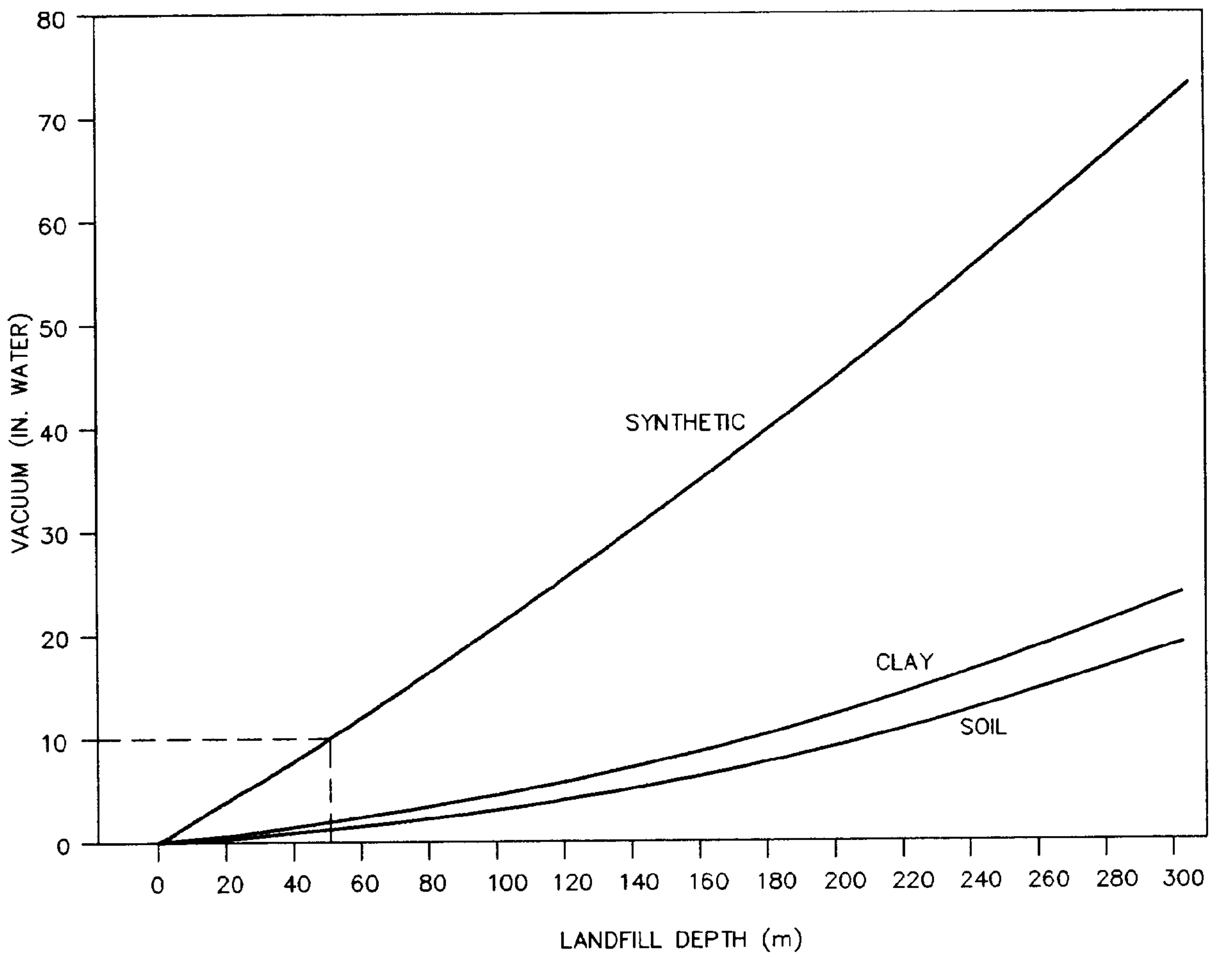
- Estimate fitting losses

MODEL LANDFILL
GAS EXTRACTION WELL SYSTEM CALCULATIONS

(1) Well Designation	(2) Well Screen Length* (ft)	(3) Estimated Flowrate per Well (cfh)	(4) Estimated Cumulative Flowrate (cfh)	(5) Lateral Section Designations	(6) Length of Lateral (ft)	(7) Lateral Diameter (1) (in)	(8) Lateral Diameter (2) (in)	(9) Selected Lateral Diameter
GW-6	30	846			160			
GW-1	28	790	846	FA	160	1.1	1.1	4
GW-7	26	733	1636	AB	160	1.5	1.6	4
GW-2	24	677	2369	BC	160	1.7	1.9	4
GW-3	41	1156	1156	G-A'	160	1.3	1.3	4
GW-8	22	620	2989	CD	160	1.9	2.1	4
GW-4	43	1213	1213	H-C'	160	1.3	1.4	4
GW-5	20	564	3553	DE	160	2	2.3	6
GW-9	41	1156	1156	I-E'	160	1.3	1.3	4
GW-10	17	479	4709	EJ	160	2.2	2.7	6
			5188	JU	125	2.3	2.8	6
GW-11	30	846						
GW-16	28	790	846	KP	160	1.1	1.1	4
GW-12	26	733	1636	PQ	160	1.5	1.6	4
GW-17	24	677	2369	QR	160	1.7	1.9	4
GW-18	41	1156	1156	L-Q'	160	1.3	1.3	4
GW-13	22	620	2989	RS	160	1.9	2.1	4
GW-19	43	1213	1213	M-R'	160	1.3	1.4	4
GW-20	20	564	3553	ST	160	2	2.3	6
GW-14	41	1156	1156	N-T'	160	1.3	1.3	4
GW-15	17	479	4709	TO	160	2.2	2.7	6
			5188	OU	125	2.3	2.8	6
SUMP								
U			10376	TO FLARE	100	3.1	4	8
TOTALS								

(1) Well Designation	(10) Gas Velocity per Well (ft/s)	(11) Gas Velocity (ft/s)	(12) Reynold's Number (NR)	(13) Friction Factor (f)	(14) Velocity Head per Well (in. H2O)	(15) Cummulative Velocity Head (in. H2O)	(16) Head Loss due to Friction (in. H2O)
GW-6	2.69						
GW-1	2.52	2.69	6.85E+03	0.02	0.001	0.002	0.019
GW-7	2.33	5.21	1.33E+04	0.02	0.001	0.006	
GW-2	2.16	7.54	1.92E+04	0.02	0.001	0.012	0.115
GW-3	3.68	3.68	9.37E+03	0.02	0.003	0.003	0.029
GW-8	0.88	9.52	2.42E+04	0.02	0	0.019	0.182
GW-4	3.86	3.86	9.83E+03	0.02	0.003	0.003	0.029
GW-5	0.8	5.03	1.92E+04	0.02	0	0.005	0.032
GW-9	3.68	3.68	9.37E+03	0.02	0.003	0.003	0.029
GW-10	0.68	6.67	2.55E+04	0.02	0	0.009	0.058
		7.34	2.80E+04	0.02		0.011	0.055
GW-11	2.69			0.02	0.002		
GW-16	2.52	2.69	6.85E+03	0.02	0.001	0.002	0.019
GW-12	2.33	5.21	1.33E+04	0.02	0.001	0.006	0.058
GW-17	2.16	7.54	1.92E+04	0.02	0.001	0.012	0.115
GW-18	3.68	3.68	9.37E+03	0.02	0.003	0.003	0.029
GW-13	0.88	9.52	2.42E+04	0.02	0	0.019	0.182
GW-19	3.86	3.86	9.83E+03	0.02	0.003	0.003	0.029
GW-20	0.8	5.03	1.92E+04	0.02	0	0.005	0.032
GW-14	3.68	3.68	9.37E+03	0.02	0.003	0.003	0.029
GW-15	0.68	6.67	2.55E+04	0.02	0	0.009	0.058
		7.34	2.80E+04	0.02	0	0.011	0.055
SUMP							
U	5.29	8.26	4.21E+04	0.02	0.006	0.014	
TOTALS							1.154

(1) Well Designation	(17) Tee #	Tee Loss	(18) Fitting Losses Valves #	Valves Loss	(19) Sumps/ Monitoring Stations	(20) Total Losses
GW-6			1	0.00163		0.00163
GW-1			1	0.00142		0.02042
GW-7			1	0.00122		0.05922
GW-2			1	0.00104		0.11604
GW-3	1	0.006	1	0.00304		0.03804
GW-8			1	0.00015		0.18215
GW-4	1	0.006	1	0.00334		0.03834
GW-5			1	0.00013		0.03213
GW-9	1	0.006	1	0.00304		0.03804
GW-10			1	0.00009		0.05809
						0.055
GW-11			1	0.00163		0.00163
GW-16			1	0.00142		0.02042
GW-12			1	0.00122		0.05922
GW-17			1	0.00104		0.11604
GW-18	1	0.006	1	0.00304		0.03804
GW-13			1	0.00015		0.18215
GW-19	1	0.006	1	0.00334		0.03834
GW-20			1	0.00013		0.03213
GW-14	1	0.006	1	0.00304		0.03804
GW-15			1	0.00009		0.05809
			1	0		0.055
SUMP					0.41	
U					0.41	0.41
TOTALS		0.036		0.02857	0.82	1.68657



MAXIMUM BLOWER VACUUM AS A FUNCTION OF LANDFILL DEPTH FOR THREE COVER TYPES

FIGURE E-4
N.T.S.
(SOURCE 3)

Gas Extraction well System Calculations

Methodology:

- Total losses for collection system
- Estimate losses for treatment system and establish delivery pressure for treatment unit
- Calculate horsepower requirement for the blower from total losses
- Use manufacturer's information to select blower that can meet both head and flow rate requirements

Calculations:

Calculations for sizing are shown below and on the following pages.

Motor Horse Power Requirements:

$$W_{SM} = \frac{Q_{TOT}\,(\Delta P_{TOT})}{3.1536 \times 10^7\,(.65)} \qquad (8)$$

$Q_{TOT} = 1.46\text{x}10^8 \frac{ft^3}{yr} \times \frac{m^3}{35.31ft^3} = 4.13\text{x}10^6 \frac{m^3}{yr}$

ΔP_{TOT} = landfill cover pressure drop + pipe header losses + treatment system losses, asumming 5 in.wc

= 10in.wc/well x 20wells + 1.22 + 1.69 + 5 = 207.91 in.wc

$= 207.91 \text{ in.wc} \times \frac{10^5 N.m^{-2}}{1020in.wc} = 20{,}380\ N.m^{-2}$

$W_{SM} = (4.13 \times \underline{10^6 m^3} \times 20{,}380\ N.m^{-2})/3.154\text{x}10^7\text{x}0.65) = \underline{4{,}111 \text{ Watts}}$

$4{,}111\ W \times \frac{HP}{746\ W} = 5.5\ HP$

Electric motors come with standard sizes, 5 7.5 HP, therefore use 7.5 HP motor.

Blower specification: 175 cfm @ 7.5 HP (add 1 blower as spare)

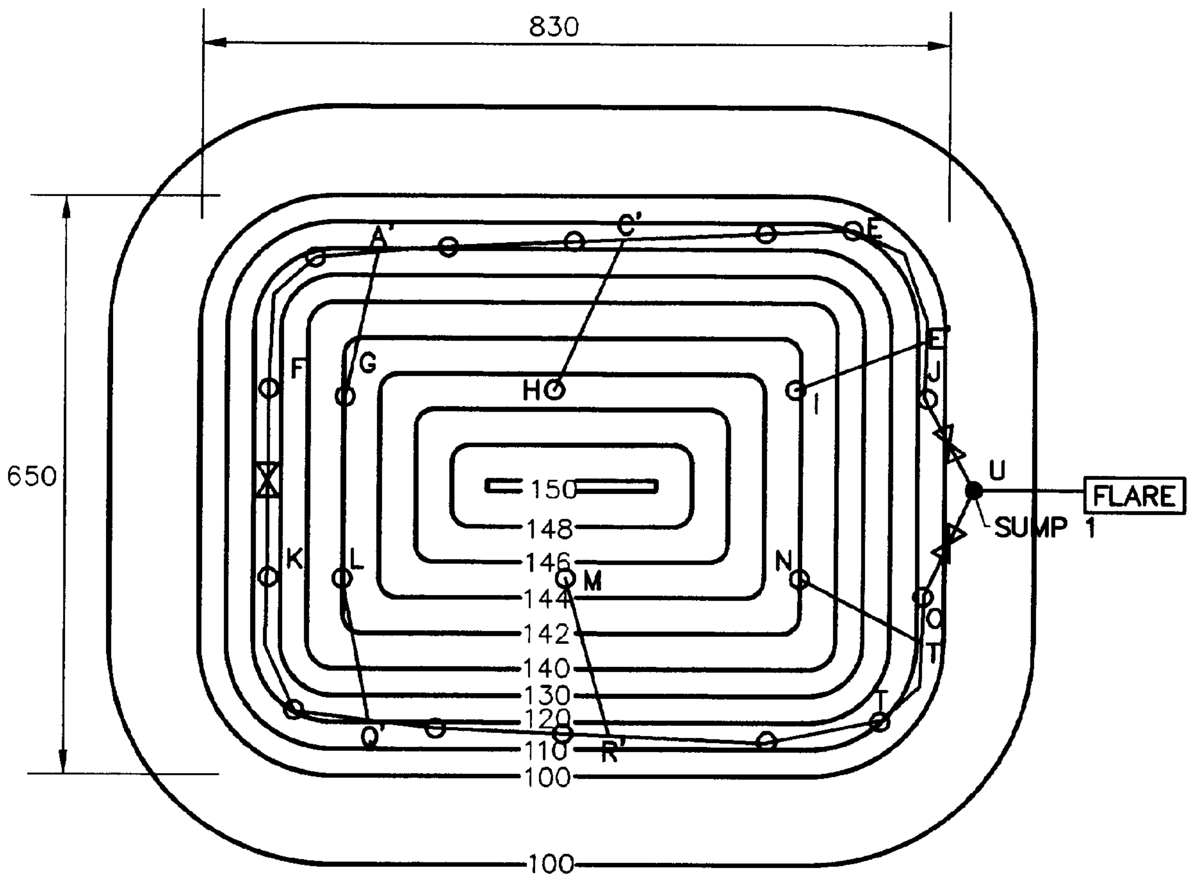


FIGURE E-5

MODEL LANDFILL LATERAL STATEMENT
H-C' HEADER SECTION REFERENCED IN CALCULATIONS

LEGEND

- GAS EXTRACTION WELL
- SUMP
- GAS LATERAL
- IN-LINE ISOLATION VALVE/ MONITORING STATION

8. Condensate Generation Rate

Assumptions:

- Landfill gas is saturated with moisture
- Landfill gas parameters as noted above
- Climatological data for the site indicates an average ambient air temperature of 55 ^{0}F
- Landfill gas density is sufficiently similar to air to use psychometric charts developed for air saturated with water
- Landfill gas condensate density is sufficiently similar to water to use psychometric charts developed for air saturated with water

Methodology:

- Determine humidity and specific volume for air saturated with water for each temperatures ranging from the assumed average ambient temperature to the maximum system temperature
- Calculate the concentration of water (condensate) entrained in the air (gas)
- Calculate the volume of water (condensate) extracted per unit time for the design gas flow rate
- Determine the maximum volume of water (condensate) produced per unit time as averaged for the year

Calculations:

Calculations for the Model Landfill - Condensate Generation can be found on the following page.

Lateral header statement used for the calculations is illustrated in Figure E-5.

MODEL LANDFILL

CONDENSATE GENERATION CALCULATIONS

Assume:	173	cfm
	100	% relative humidity
	55	degrees F in piping
		density of condensate = density of water

Calculations:

1. Water Concentration (# water/cu ft wet air) = Humidity (# water/# dry air)/Specific Volume (cu ft wet air/# dry air)
2. Volume of Water Extracted (gallons/day) = # water/cu ft wet air * flowrate (cfm) * 1440 (minutes/day) * 0.12 (gallons/#)
3. Volume of Water Condensed (gallons/day) = Volume of Water Extracted at X degrees - Volume of Water Extracted at 55 degrees.

Temperature	Humidity	Spec. Vol.	1. Water Concentration	2. Volume of Water Extracted, gallons/day	3. Volume of WaterCondensed, gallons/day
55	0.0093	13.17	7.06e-04	21.11	0
60	0.01108	13.329	8.31e-04	24.85	3.74
65	0.01326	13.504	9.82e-04	29.35	8.24
70	0.01581	13.688	1.16e-03	34.53	13.42
75	0.01881	13.882	1.36e-03	40.51	19.40
80	0.02231	14.088	1.58e-03	47.34	26.23
85	0.02639	14.309	1.84e-03	55.13	34.02
90	0.03115	14.547	2.14e-03	64.01	42.90
95	0.03668	14.804	2.48e-03	74.07	52.96
100	0.04312	15.083	2.86e-03	85.46	64.35
105	0.05061	15.389	3.29e-03	98.31	77.20
110	0.05932	15.725	3.77e-03	112.77	91.66